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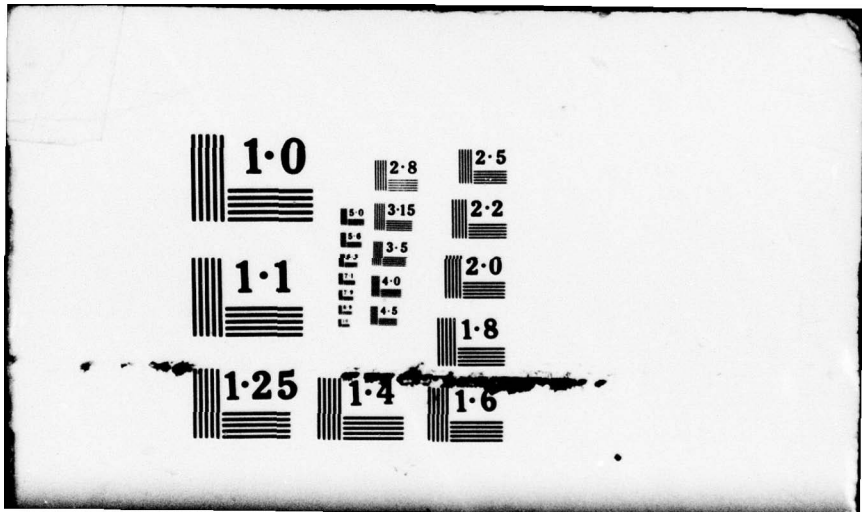
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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: [redacted]R-CR-77041 (19) (18) DRC PM-DR

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle) (6)
An Aerial Radiological Survey of the Weldon Spring Chemical Plant (Saint Charles, Missouri) Date of Survey: 11-14 May 1976.

5. TYPE OF REPORT & PERIOD COVERED (9)
Final rept.

6. PERFORMING ORG. REPORT NUMBER
EGG-1183-1700

7. AUTHOR(s) (10)
Joel E. Jobst

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
EG&G Inc
680 E. Sunset Road
Las Vegas, NV 89119
702 [redacted]

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (12) 40p.

11. CONTROLLING OFFICE NAME AND ADDRESS
OFFICE OF THE PROJECT MANAGER FOR CHEMICAL DEMILITARIZATION AND INSTALLATION RESTORATION
ABERDEEN PROVING GROUND, MARYLAND 21010 (11)

12. REPORT DATE
Jan[redacted]77

13. NUMBER OF PAGES
41

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
Nevada Operations Office
US Energy Research and Development Administration
(now Department of Energy)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for Public Release: Distribution Unlimited

(14) EGG-1183-1700

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(15) EY-76-C-08-1183

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Radiological Survey	Helicopter
Weldon Spring Chemical Plant	Gamma Grass Count
Aerial Survey	Thallium Radiation Isopleths
Radiological Contamination	Uranium
Sodium Iodid Detectors	Thorium
	St Charles County, MO

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
An Aerial Radiological Survey of the Weldon Spring Chemical Plant was conducted in May 1976. Gamma grass count and thallium radiation isopleths were generated. All contamination is on the site or within 200m of the fence line.

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LEVEL II

EGG-1183-1700
January 1977

AN AERIAL RADIOLOGICAL SURVEY OF THE

WELDON SPRING CHEMICAL PLANT

(ST. CHARLES, MISSOURI)

DATE OF SURVEY: 11-14 MAY 1976

by
Joel E. Jobst

Approved for Publication

Louis G. Sasso, Manager
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Radiation and Environmental
Sciences Department

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Classification Officer

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ABSTRACT

An aerial radiological survey was conducted over the Weldon Spring Chemical Plant, which is in St. Charles County, thirty miles from St. Louis, Missouri. The survey was performed in May 1976 using sodium iodide detectors mounted in a helicopter. Gamma gross count and thallium radiation isopleths were superposed on an aerial photograph of the Site. Several concentrations of uranium and thorium waste were located. All contaminants were on the Site or within 200m of the fence line. The survey was sponsored by the U. S. Department of the Army, authorized by the U. S. Energy Research and Development Administration, and conducted by EG&G, Incorporated of Las Vegas, Nevada.

ACKNOWLEDGMENTS

The author wishes to acknowledge the support of an extremely competent field crew of technicians and scientists who performed the survey of the Weldon Spring Chemical Plant: Marvin Wingrove, pilot; Michael Sevart, navigator; James Cates, computer specialist; Thomas Hess, electronic technician.

The author also acknowledges the assistance of those who helped analyze the data and edit the text: Thane Hendricks, W. John Tipton and T. P. Stuart.

Finally the author wishes to thank Captain Glenn Niedermeyer, James Zarzycki, and Robert York of the Department of the Army for their assistance in planning this operation and their outstanding cooperation during the survey and in the preparation of this report.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1. INTRODUCTION

The Energy Research and Development Administration (ERDA) operates an aerial surveillance operation called AMS: Aerial Measuring Systems.[1] From its inception in 1960 the program has included radiological surveys of nuclear power plants, processing plants for nuclear materials, and research laboratories. AMS aircraft have been deployed to nuclear accident sites or in searches for lost radioisotopes. They were routinely used during launch operations for Apollo, Viking and other space vehicles which contained radioisotope thermal generators. AMS aircraft also have metric cameras and multispectral camera arrays for aerial photography, a thermal mapper for infrared imagery, a broad array of meteorological sensors, and air sampling systems for particulate and whole gas measurements.

This system is maintained and operated for ERDA by EG&G, Incorporated. At the request of federal agencies, such as the Nuclear Regulatory Commission, or state agencies, AMS is deployed for various aerial survey operations.

In late October, 1975, ERDA was requested by the Department of the Army[2] (DA) to conduct an aerial survey of the Weldon Spring Chemical Plant near St. Charles, Missouri. On 22 November 1975 this survey was conducted at an altitude of 150m from a Beechcraft A-100 equipped for radiological surveillance. The results[3] indicated several highly-localized distributions of contaminants on site, with the possibility of off-site contamination.

To obtain finer resolution the Army[2] subsequently requested that another aerial survey be performed over the Site at lower altitude, with closer line spacing. Beginning on 11 May 1976, the AMS conducted a 4-day survey with a Hughes H-500 helicopter. The altitude and line-spacing were both 30m.

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1 Formerly the Aerial Radiological Measurement System (ARMS).

2 Office of the Department of the Army, Project Manager for Chemical Demilitarization and Installation Restoration, AMCPM-DRR, Aberdeen Proving Ground, MD 21010.

3 Jobst, J.E., "Aerial Radiological Survey of the Weldon Spring Chemical Plant (St. Charles, Missouri). Date of Survey: 22 November 1975, "Report No. EGG-1183-1688, EG&G, Incorporated, Las Vegas, Nevada, 21 April 1976.

This report discusses the survey plan and the results in considerable detail. The equipment[4] and the data analysis techniques[5] will be discussed only briefly here, since they are carefully presented elsewhere.

2. THE SITE

The Weldon Spring Chemical Plant is located in St. Charles County, Missouri, approximately 13 miles southwest of the city of St. Charles and 25 miles west of St. Louis. It is on Missouri State Highway 94, less than 2 miles from its juncture with U. S. Route 40. In the aerial photograph shown in Fig. 1 the facility fence line is graphically emphasized.

From 1957 to 1966 the United States Atomic Energy Commission (AEC) used this Facility to convert uranium ore concentrates and to recycle scrap into uranium trioxide, uranium tetrafluoride, and uranium metal. Some processing of thorium residues was also undertaken.

Since 1967 the Plant has been maintained by Kansas City District Engineer personnel on Site, with no manufacturing operations of any sort. It contains 169.08 acres under the jurisdiction of the Department of the Army. The remaining 50.65 acres within the fence line are the responsibility of the Energy Research and Development Administration (ERDA). The Army also has control over an additional 32 acre sewer easement from the Plant site to the Missouri River.

The ERDA portion of the site contains primarily the four raffinate pits (numbered in Fig. 2) and the land surrounding them. These are earth-diked enclosures. Pits 1 and 2 contain semi-solid refinery waste with a thin, hard crust on the surface. Pits 3 and 4 are largely water-filled to a depth of a few feet. They contain materials similar to those in pits 1 and 2; in addition there are tons of solid waste and uncounted numbers of 55-gallon drums.

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4 Boyns, P.K., "The Aerial Radiological Measuring System (ARMS): Systems, Procedures and Sensitivity (1976)," Report No. EGG-1183 1691, EG&G, Incorporated, Las Vegas, Nevada, July 1976.

5 Ibid and Jobst op. cit.

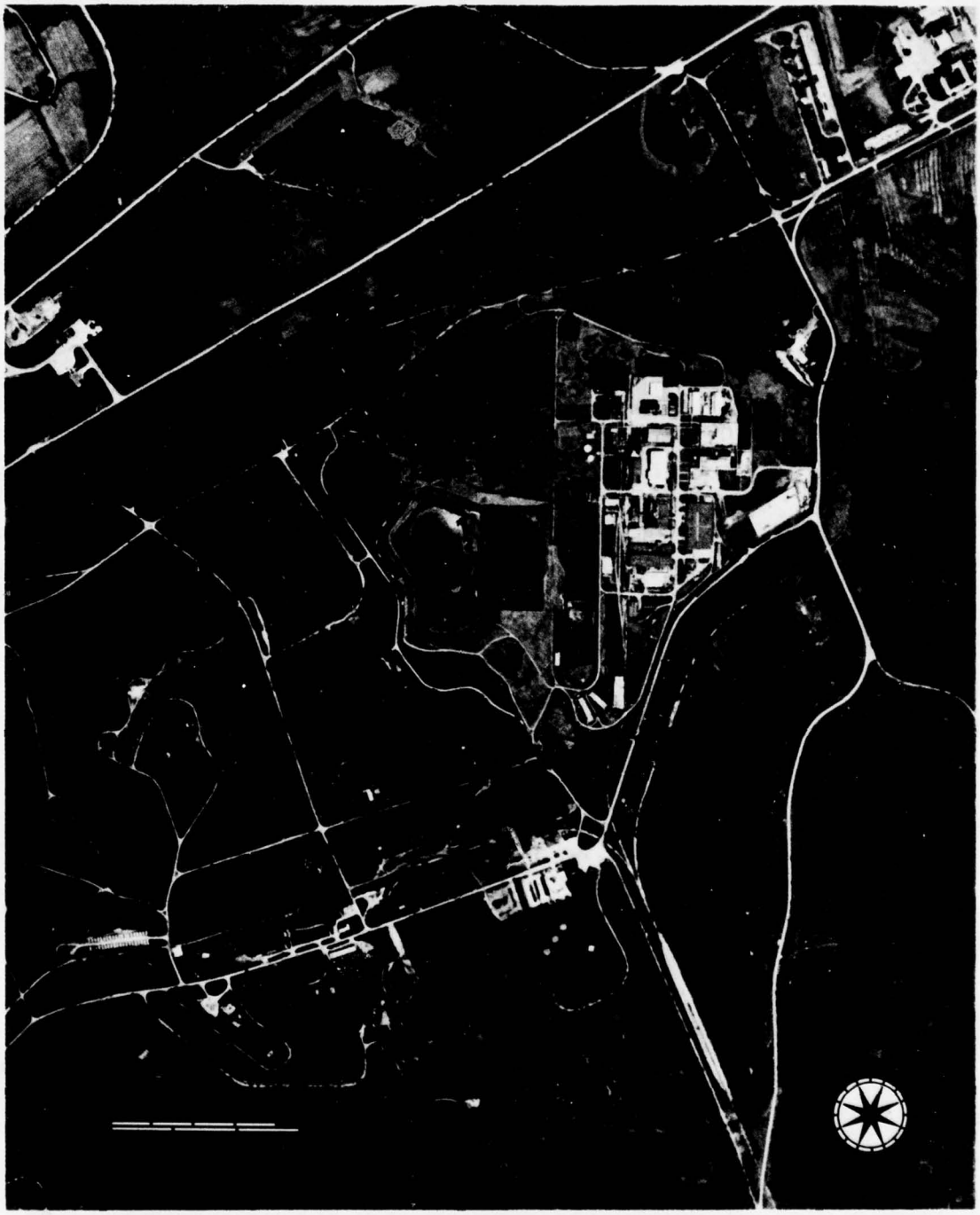
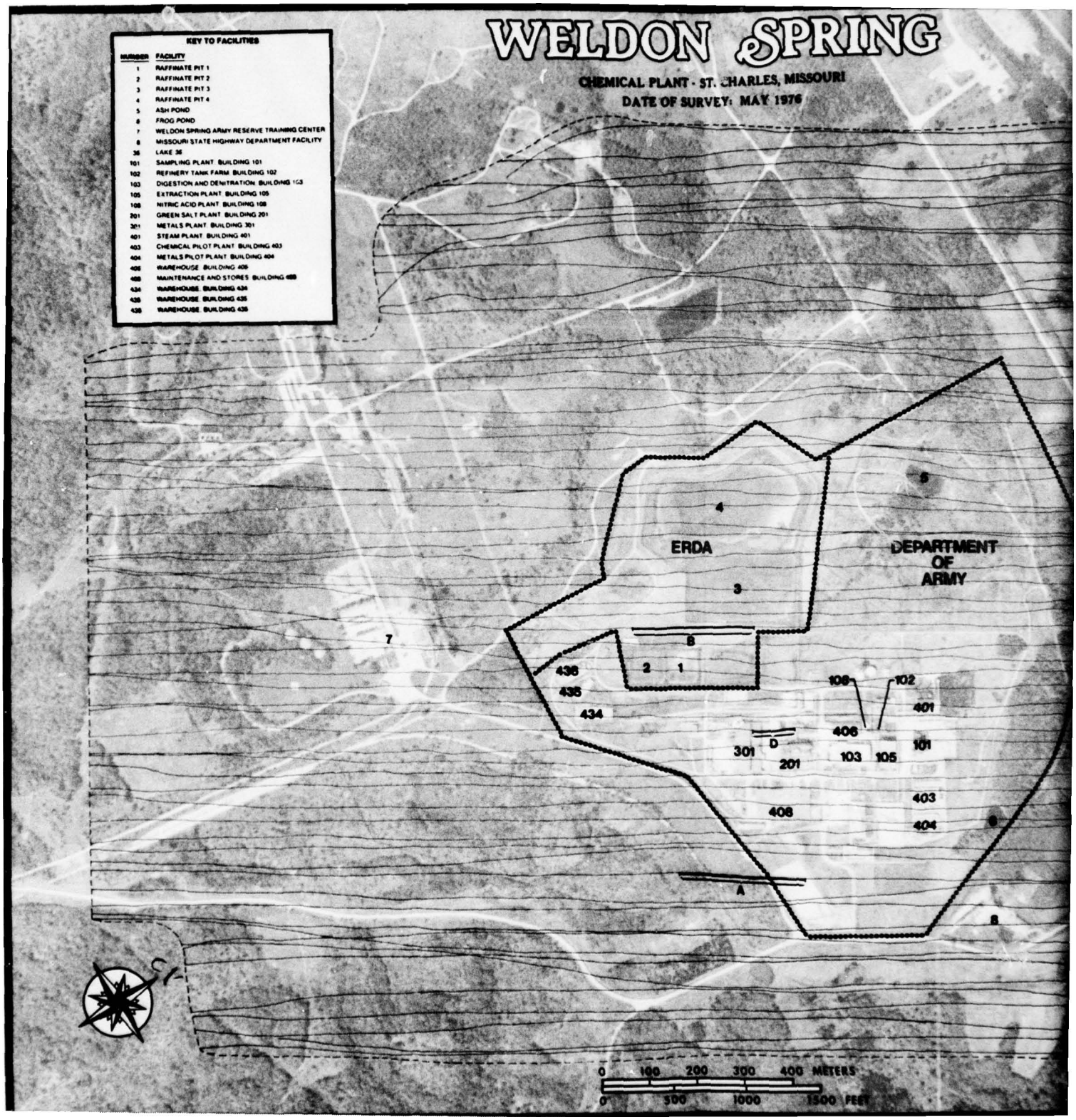
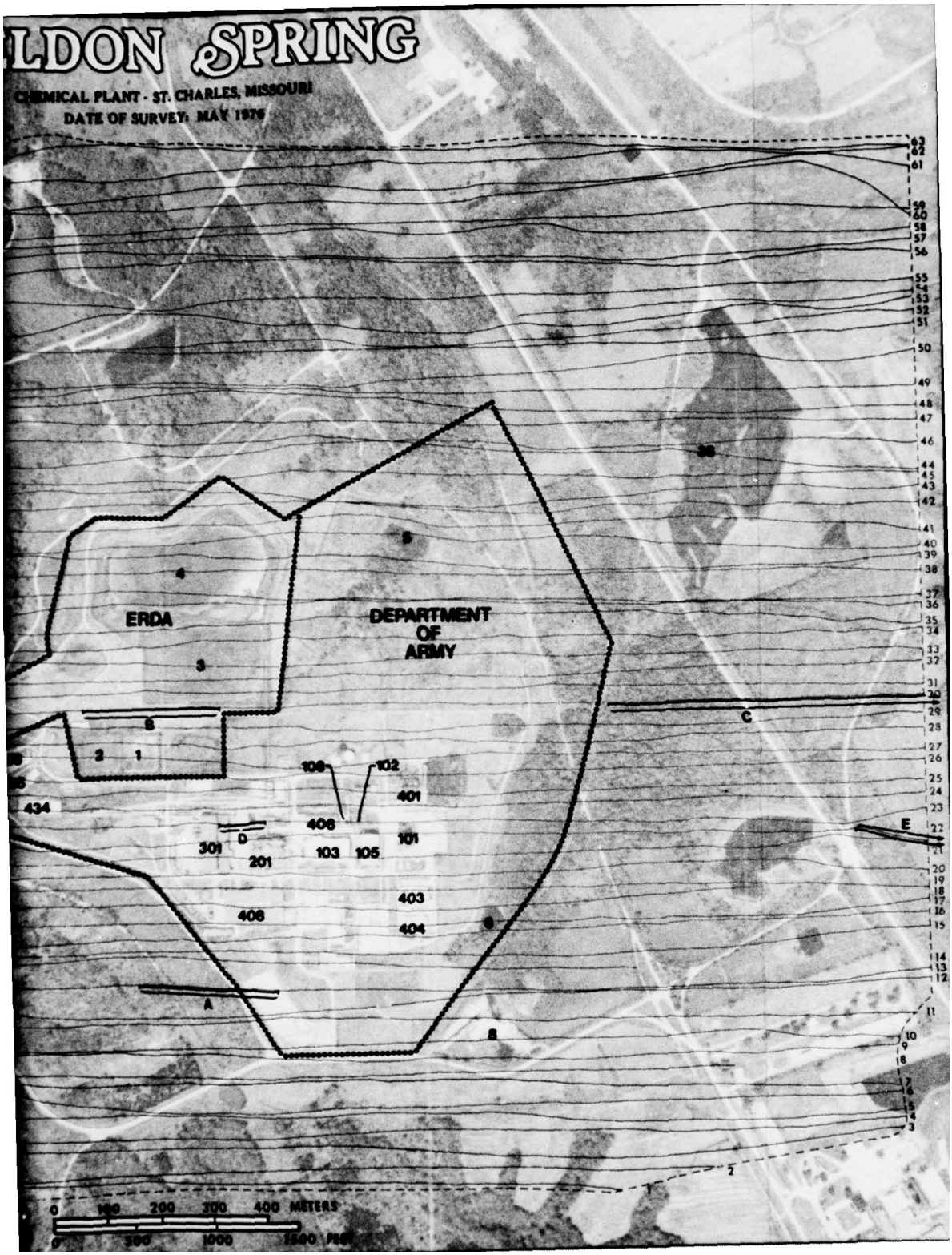


Figure 1. The WSCP site contains 219.73 acres (169.08 Army, 50.65 ERDA). Since the fencelines are invisible, the Plant boundary has been graphically highlighted. Most of the 32 acre easement to the Missouri River is not shown in this photograph.


WELDON SPRING
CHEMICAL PLANT - ST. CHARLES, MISSOURI
DATE OF SURVEY: MAY 1976
KEY TO FACILITIES
NUMBER FACILITY
1 RAFFINATE PIT 1
2 RAFFINATE PIT 2
3 RAFFINATE PIT 3
4 RAFFINATE PIT 4
5 ASH POND
6 FROG POND
7 WELDON SPRING ARMY RESERVE TRAINING CENTER
8 MISSOURI STATE HIGHWAY DEPARTMENT FACILITY
36 LAKE 36
101 SAMPLING PLANT BUILDING 101
102 REFINERY TANK FARM BUILDING 102
103 DIGESTION AND DENITRATION BUILDING 103
105 EXTRACTION PLANT BUILDING 105
108 NITRIC ACID PLANT BUILDING 108
201 GREEN SALT PLANT BUILDING 201
301 METALS PLANT BUILDING 301
401 STEAM PLANT BUILDING 401
403 CHEMICAL PILOT PLANT BUILDING 403
404 METALS PILOT PLANT BUILDING 404
406 WAREHOUSE BUILDING 406
408 MAINTENANCE AND STORES BUILDING 408
434 WAREHOUSE BUILDING 434
435 WAREHOUSE BUILDING 435
436 WAREHOUSE BUILDING 436
ERDA
DEPARTMENT OF ARMY
0 100 200 300 400 METERS
0 500 1000 1500 FEET


LDON SPRING
CHEMICAL PLANT - ST. CHARLES, MISSOURI
DATE OF SURVEY: MAY 1976
ERDA
DEPARTMENT OF ARMY
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3
5
6
2
1
A
B
C
D
E
434
301
201
108
102
401
406
103
105
101
403
408
404
0 100 200 300 400 METERS
0 500 1000 1500 FEET

Detailed color photographs of the Plant also show dumping areas scattered over the Army portion of the Site. In situ inspection indicates that a broad variety of materials, loose and in containers, were disposed of in many areas. Some are now partially hidden by vegetation, shrubs and sizable trees.

The fenceline is maintained by Kansas City District Engineer personnel on Site. Access can be gained only by DA permission. Prior to this survey it had been assumed that all in situ disposal areas were within the fenceline. It is now known that at least one dump was outside the Weldon Spring Chemical Plant fence, but still on property controlled by the DA.

Even though the Weldon Plant is small, the Site lies astride two major watersheds. The north portion of Site drains northward into the Mississippi River. The south portion drains into the Missouri River.

3. THE SURVEY PLAN

A highly-enlarged aerial photo of the Weldon Spring site was used to lay out survey lines. These were spaced 30 meters apart. In all cases survey coverage was extended at least 250m beyond the boundary fence of the facility. The flight paths actually flown, at an altitude of 30±3m, are shown in Fig. 2. Figure 2 also shows the boundaries of the ERDA and DA areas on the Site. Sixty-three lines were flown directly over the Site, or the land just outside the fence. Two more lines were flown to cover known drainage paths into the Mississippi and Missouri Rivers.

4. AIRBORNE EQUIPMENT

A Hughes H-500 helicopter, shown in Fig. 3, was used for this low-altitude survey of the Weldon Spring Chemical Plant. The H-500 carried a crew of 2. It employed a light-weight version of the REDAR[6] System previously employed in the A-100 survey of the Site. Two pods, each containing ten 12.7-cm diameter by 5.1-cm thick NaI (Tl) detectors, were mounted on the sides of the helicopter. Gamma ray signals from the 20 detectors were summed, routed through an analog-to-digital converter and a pulse-height analyzer. Gamma spectra were accumulated in 3-second records and recorded on 1/2-in. magnetic tape.

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6 Radiation and Environmental Data Acquisition and Recording.

Figure 3. The Hughes H-500 helicopter is operated by a pilot and a navigator. The latter also operates the REDAR system in the rear compartment. Each detector pod contains ten sodium iodide detectors.

The helicopter position was established with two systems: a Trisponder/202A microwave ranging system and an AL-101 radio altimeter. The Trisponder master station, mounted in the helicopter, interrogated two remote transceivers mounted on towers outside the survey area. By measuring the round-trip propagation time between the master and remote stations, the master computed the distance to each. These distances were recorded on mag tape each second; in subsequent computer processing they were converted to position coordinates.

The radio altimeter similarly measured the time lag for the return of a pulsed signal and converted this to aircraft altitude. For altitudes up to 150m the accuracy was ± 0.6m or ±2%, whichever is greater. These data were also recorded on mag tape so that any variations in gamma signal strength caused by altitude fluctuation could be accurately compensated.

The detectors and electronic systems which accumulate and record the data are described only briefly here. They are described in considerable detail in previous reports.[7]

5. DATA PROCESSING SYSTEM

Data processing was begun in the field with the REDAC System: Radiation and Environmental Data Analyzer and Computer. This is a computer analysis laboratory, mounted in a mobile van (cp. Fig. 4). As in the previous survey the van and the aircraft were based at the Spirit of St. Louis Airport, Chesterfield, Missouri.

The REDAC (cp. Fig. 5) consists primarily of two Cipher Data tape drives,[8] A NOVA 840 computer,[9] two CalComp plotters,[10] and a CRT display screen[11] with a hard copier.[11] The computer has a 32k-word core memory and an additional 1.2×10^6-word disc memory. An extensive collection of software routines is available for data processing.

---

7 Boyns, op. cit. and Jobst, op. cit.

8 Cipher Data Products Company.

9 Data General Corporation.

10 California Computer Products, Inc.

11 Tektronix Corporation.

Figure 4. The heart of the REDAC system is a NOVA 840 computer. Sophisticated software routines allow preliminary isopleths to be prepared in the field. Gamma spectra may be obtained immediately after the aircraft returns from a mission.

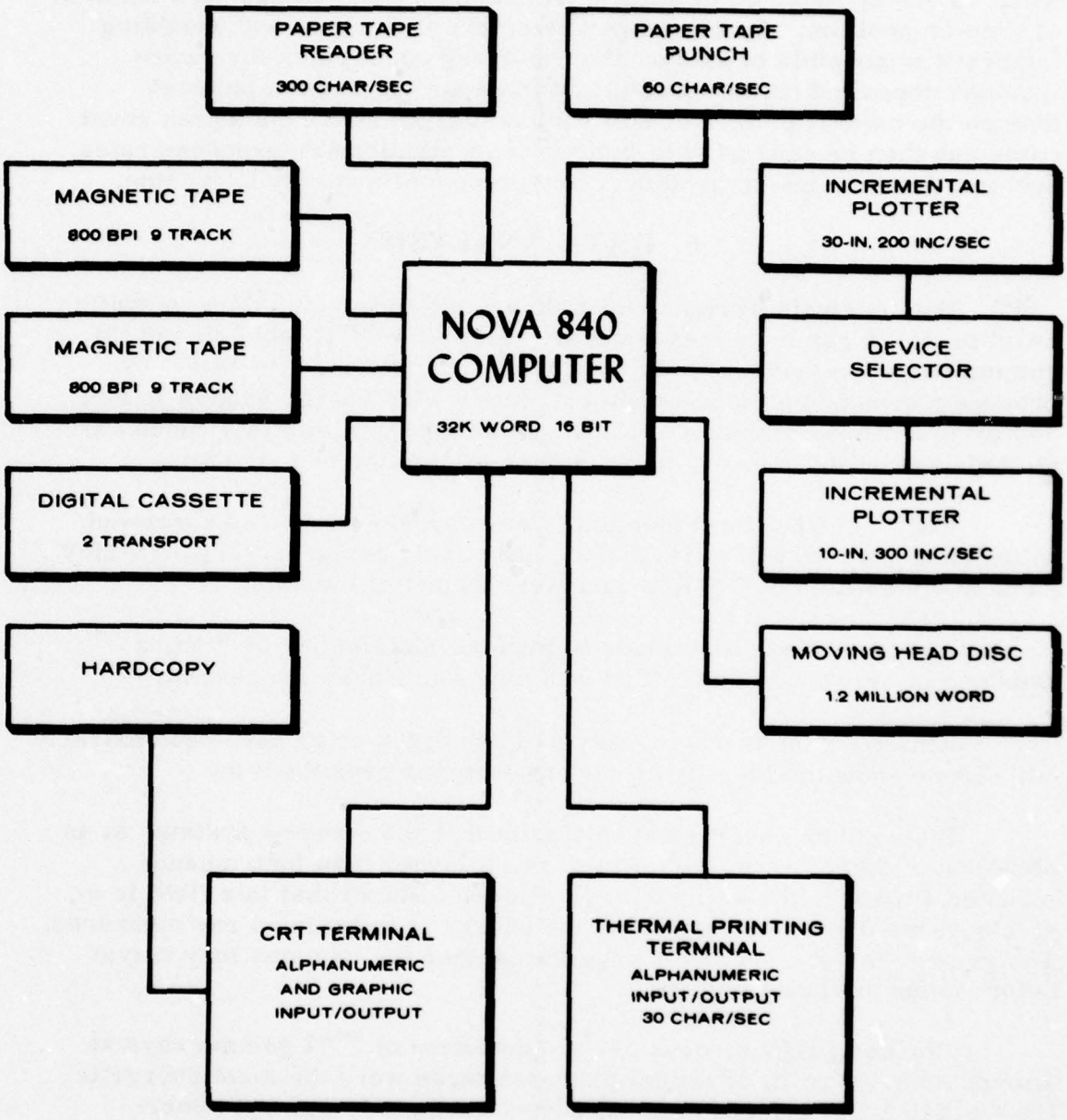


Figure 5. A block diagram of the REDAC (Radiation and Environmental Data Analyzer and Computer) System.

Gamma spectral windows can be selected for any portion of the spectrum between 50 keV and 3 MeV. Weighted combinations of such windows can be summed or subtracted and the result plotted as a function of time or position. By the proper selection of windows and weighting factors it is possible to extract the photopeak count rates for radioisotopes deposited on the terrain by human activity. Such isotopes disturb the natural pattern of soil radioactivity. These photopeak count rates can then be converted to isotope concentrations or exposure rates. Spectral data can be summed over any portion of a survey flight line.

6. DATA ANALYSIS

Data analysis work has been directed to producing three specific results: (1) a gamma gross count isopleth, (2) a ^{208}Tl isopleth and (3) gamma radiation spectra which adequately characterize the Site. To produce a gross count isopleth an extremely wide energy window is set: 50 keV to 3 MeV. The sum of all the gamma rays within this window is plotted, second-by-second, as a function of position over the Site.

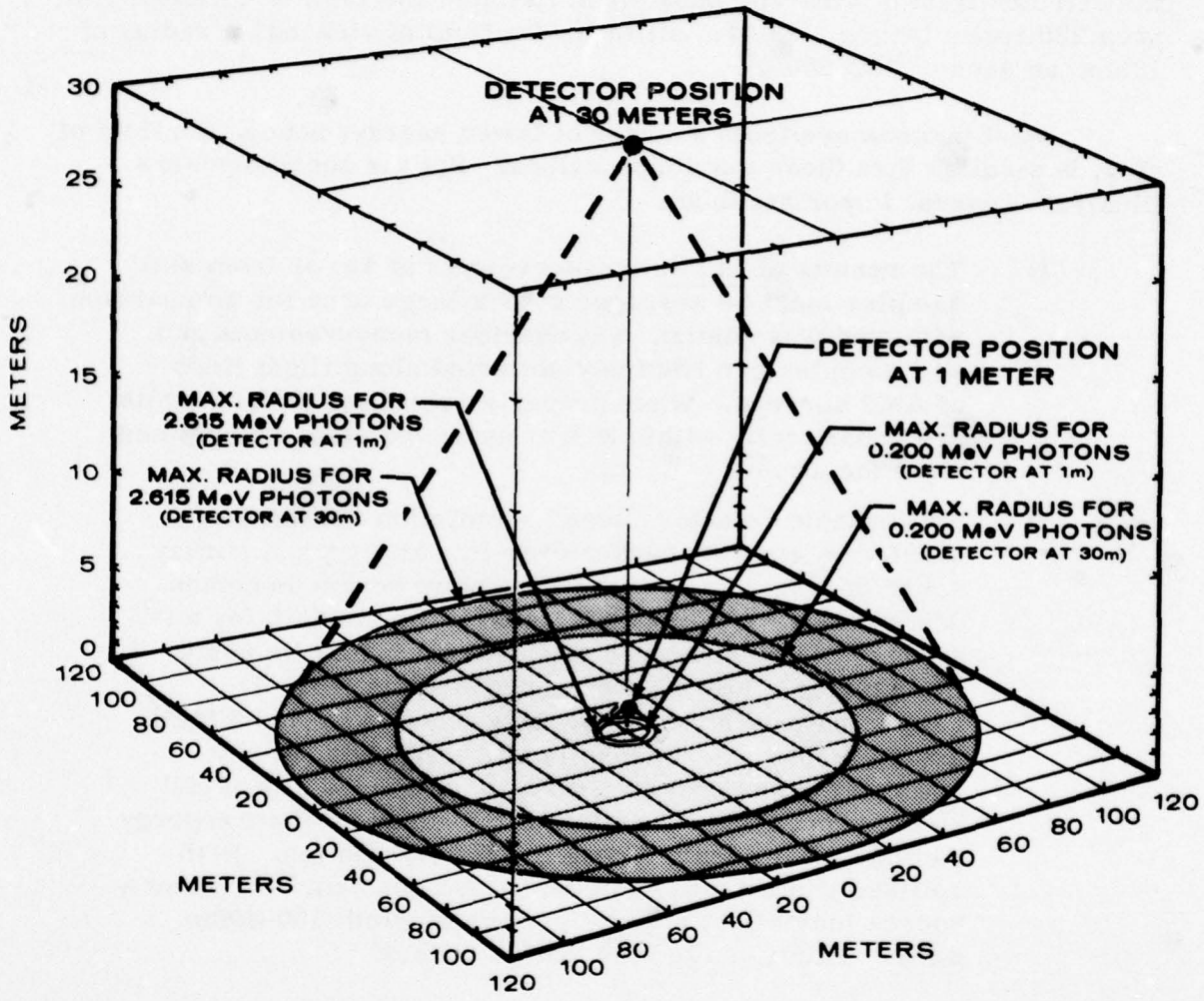
The ^{208}Tl (thallium) isopleth is similar; the window is narrowed to the range $2.4 \leq E\gamma \leq 2.9$ MeV. This effectively captures the 2.615-MeV gamma ray emitted by ^{208}Tl, a daughter product of thorium.

An attempt was also made to map the distribution of ^{214}Bi, a daughter of uranium. This effort was only marginally successful.

Finally, gamma-ray energy as intensity spectra have been extracted. These show the identity of various isotopes over the Site.

It should be observed at this point that the detector system, at an elevation of 30m, has a field of view much larger than instruments mounted 1m above the soil surface. Figure 6 shows that this field is a circle whose diameter depends on the energy of the gamma ray measured. The greater the gamma ray energy the farther the gammas may travel before being attenuated by air.

For comparison, consider the detection of ^{208}Tl gamma rays at 1m and 30m. For all practical purposes these were the most energetic ($E\gamma = 2.615$ MeV) gamma rays measured during this survey. Some thallium photons will collide with atoms of gas or suspended particulate matter between the ground and the detector. Then photons of degraded energy may be detected ("collided photons"). But these have lost their identity as "thallium photons." Approximately 90% of the uncollided



NOTE: FOR ILLUSTRATION CLARITY, VERTICAL AND HORIZONTAL GRIDS ARE NOT TO THE SAME SCALE.

Figure 6. The detector field of view is a circle from which 90% of the detected photons emanate. The field varies with photon energy. The 30m and 1m fields are shown here.

photons arriving at the detector (the "field of view") are emitted from a circle 7.93m in radius when the detector is 1m above ground. However, at the survey altitude of 30m this circle has a radius of 118.1m. At 1m the detector field of view encloses 198m^2; at 30m the field is 43,800m^2, an area 220 times larger. At 61m altitude, the field of view has a radius of 183m, an area of 152,200m^2.

Most photons are from sources of lower energy; hence, the field of view is smaller than these maximum values. But the above numbers illustrate several important facts.

1) The results of in situ measurements at 1m or from soil samples must be averaged over a large area for comparison with aerial isopleths. Ion chamber measurements and soil samples are routinely collected along flight lines of AMS surveys. When properly averaged, these results are consistently within 20% of exposure rates determined from the air.[12]

2) An airborne detector "sees" a radiation source long before the aircraft passes over it. At a typical survey speed of (28 m/sec), a thallium point source becomes detectable several seconds away. The isopleth for a strong ^{208}Tl point source on the surface may be 500m in diameter. For a gross count isopleth (Fig. 7) gamma rays of all energies between 50 keV and 3 MeV are collected. An intense localized source, of any energy, generates both a direct, uncollided signal and an indirect signal. The latter is caused by lower-energy gammas scattered from the primary radiation. Both collided and uncollided gammas are counted. An intense source may affect a gross gamma isopleth 300-400m away. This is called the "shine" effect.

12 Dr. Larry Franks, EG&G, Inc., Santa Barbara, CA, private communication.


WELDON SPRING
CHEMICAL PLANT - ST. CHARLES, MISSOURI
DATE OF SURVEY: MAY 1976
CONVERSION SCALE
LETTER LABEL
GAMMA EXPOSURE RATE AT 1 METER LEVEL*
A ≤09
B 09 - 18
C 18 - 27
D 27 - 36
E 36 - 45
F 45 - 54
G 54 - 63
H 63 - 72
I 72 - 122
J 122 - 244
K 244 - 488
L 488 - 976
M 976 - 203
N 203 - 407
O 407 - 813
P 813 - 1626
*This isopleth shows gamma exposure rate at 1m above ground level due to terrestrial sources only. Cosmic rays add an additional 4 μR h
0 100 200 300 400 METERS
0 500 1000 1500 FEET


ELDON SPRING
CHEMICAL PLANT - ST. CHARLES, MISSOURI
DATE OF SURVEY: MAY 1976
0 100 200 300 400 METERS

7. RESULTS

7.1 GROSS COUNT GAMMA ISOPLETH

Figure 7 shows the intensity of gamma rays over the site. The energy window is wide: 50 keV to 3 MeV. This excludes X-rays and low energy gammas on the low end, some high energy cosmic rays on the upper end. The count rate within the window is converted to microroentgen per hour (μR/h) at a distance of 1m above the ground. This is an effective measure of exposure rate to critical body organs.

Note that the first eight steps in the conversion scale are closely spaced, differing by only 0.9 μR/h. This was designed to show subtle variations in the natural radiation levels surrounding the WSCP. Step 1 is 5.6 times as broad as the others. Levels J through P have a maximum double that of the previous interval. Additional levels in the upper portion of the scale would have contributed little additional information to the isopleth.

Data shown in Fig. 7 represent gamma exposure due to terrestrial sources only. On each of the four days that data were accumulated for this isopleth, a background flight was made over the Missouri River. Count rates (over the 0.050-3.0 MeV window) ranged from 690 to 1210 counts/second. This background was due to sources within the aircraft and detectors, radon and thoron gas[13] in the atmosphere and cosmic rays. It was subtracted to produce an isopleth which characterizes terrestrial sources only.

Cosmic rays vary in intensity, having daily, seasonal and annual fluctuations. An average rate of approximately 4 μR/h can be added to this isopleth to include their effects.[14] Radon and thoron are continuously

---

13 Radon (^{222}Rn) is a gas with a 3.8229-day half-life which results from the decay of natural uranium (^{238}U) in the soil. Thoron (^{220}Rn) is also a gas, with a 54.5-second half-life, resulting from the decay of natural thorium (^{232}Th). Both escape from the soil and contribute to airborne background.

14 Liboff, A.R., "Cosmic Ray Ionization in the Lower Atmosphere, Proceedings of the Second International Symposium on the Natural Radiation Environment, CONF-720805=P1, National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia, 22161, pp. 55-67.

released to the atmosphere. Primary contributors to atmospheric radiation are two radon daughters: ^{214}Pb and ^{214}Bi. Radon and thoron emission from the ground and distribution in the atmosphere depend on barometric pressure, wind speed and direction, temperature, soil moisture, soil condition and other parameters.

Typically, however, ^{222}Rn daughters in the air contribute only 0.1 μR/h to the total exposure rate at 1m.[15] They contribute, under normal atmospheric turbulent diffusion conditions, only about 1-2% of the total exposure rate at one meter above ground. The atmosphere does, however, contain a considerable inventory of radon daughters under normal conditions. A heavy rainfall can wash out much of this particulate material and deposit it on the ground. This results, of course, in a temporary decrease in the atmospheric contribution, an increase in ground level exposure rate. Under such conditions the exposure rate at 1m may increase by 0.5 to 4 μR/h.[16] The contributions of thoron and its daughters are minor compared to radon.

Hence, under normal conditions, in situ measurements at 1m will yield data which need not be compensated for radon effects unless extremely accurate results are required. Cosmic ray contributions, however, will have to be subtracted for comparison with the present isopleth.

The most intense radiation sources on the Weldon Spring site are along the northeast boundaries of Raffinate Pits 3 and 4 (cp. Fig. 7). The P-level isopleth observed on Pit 4 may dominate the map for a distance of 350m. Proceeding directly west of the P contour one observes this as the minimum distance to an F contour (background). Intense sources, such as the N level on Pit 3 and the O level on Pit 2 will obviously perturb the contour pattern of a nearby intense source. Nearby weak sources may, however, be completely masked by the shine effect previously discussed. Some lower level sources may cause only small perturbations in the contour pattern around an intense source. Note, for example, the unusual shape of the L contour north of Pit 4.

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15 Beck, H. L., "The Physics of Environmental Gamma Radiation Fields," CONF-720805-P1, op. cit., pp. 101-133.

16 Beck, H. L., May 1974, "Gamma Radiation From Radon Daughters in the Atmosphere," J. Geophysical Res., 79: 2215-21.

The J level 500m north of Pit 4 (along the north boundary of the Site) may indicate a source partially outside the fenceline. The H and I contours may simply be shine effect. On the other hand they may indicate partial dispersion of radioactive materials dumped within the J contour. The detector averages the exposure rate over a circle up to 500m in diameter. Only detailed measurements at 1m elevation and/or soil samples can resolve this question.

Water and vegetation may provide attenuation of the natural radioactivity in the soil. This is most evident over Lake 36, where the level drops to less than 1 μR/h. For most cases the normal soil background is 4-6 μR/h, i.e. an F level. Barren plowed fields tend to show a G level, for two reasons: 1) all attenuation has been removed and 2) potassium-rich fertilizers contain ^{40}K, a radioactive isotope. Dense grasses, trees or swampy areas attenuate natural levels to an E or even a D level. But a G level is probably a natural excursion from the normal level.

Since the H level indicates an unnaturally high level, areas so labeled should be the starting points for in situ measurements. There is an H level 200m northeast of the small Site parking lot. This appears to identify a concentration of asphalt or aggregate used for road-building. From present data, however, it cannot be established whether the activity is Site-related.

Proceeding clockwise, we note excursions of the H and I contours over the fence-line in an area southeast of Pits 1 and 2. Since drainage from the Pits and the Imhoff Tank flows southeast to the Missouri, these excursions should be carefully sampled.

Southwest of Pits 1 and 2 a strong lobe of the J contour projects to the fence-line. The H and I contours are substantially outside the fence-line at this point. These regions should be the subject of additional study. Of particular note is an I contour 300m southwest of Pit 2. Because of its isolation from the I contour surrounding the entire Plant, this small region should definitely be examined. Preliminary investigations have shown that a waste dump was located in this area at one time.

In areas west and northwest of the Plant contour levels as high as K overlap the WSCP fence-line. The overlaps are probably shine from the extraordinary activity in Pit 4. Nevertheless, because of their proximity to this intense activity they should be carefully examined. Shine from the pits can easily mask dispersions of measurable intensity below the helicopter.

Any isopleth contour at the level H(6.3-7.2 μR/h) or above represents abnormal activity. Careful inspection of the gross count and thallium isopleths shows that such abnormal activity is within 200m of the Plant fence-line. Most of the excursions were probably caused by the shine effect. But the one exception noted above indicates that in situ measurements should be extended out to 200m from the fence in suspicious or ambiguous areas.

During the planning stages of this survey some concern was expressed over major drainage paths to surrounding areas. Two special flights were made: 1) from Raffinate Pits 1 and 2 in a southeasterly direction to the Missouri River and 2) from the northwest quarter of the Site in a northerly direction. The latter flight followed drainage paths into Lake 35 and was continued on around the Lake.

Figure 8 shows the gross count exposure rate levels measured on these special flights. The survey altitude from Pits 1 and 2 to the Missouri River was 60m. The results are normalized to 1m as in Fig. 7. Approximately 90% of the 0.200 MeV photons detected came from a circle 230m in diameter; for 2.615 MeV photons the diameter is 365m. For the path shown (365m wide) activity levels are high only nears Pits 1 and 2. The nominal F-level activity is attenuated to an E by thick tree cover down to the River. Data over the River (not shown) dropped sharply to an A.

The route to and around Lake 35 was flown at 30m. The diameter of the field of view is reduced to 155m at 0.200 MeV, 235m at 2.615 MeV. Where the flight path (235m wide) was over marshes or the Lake itself, the level dropped to a D or C.

These special flights show that no measurable quantities of radioactive material have been transported extensive distances off site. Water and soil samples in all drainage stream beds may be desirable to confirm these findings.

7.2 THALLIUM-208 GAMMA ISOPLETH

To prepare the ^{208}Tl isopleth only a portion of the data plotted on the gross gamma isopleth was selected. The energy window was narrowed to the region: $2.4 \leq E\gamma \leq 2.9$ MeV. This effectively captured the highest (in energy) natural gamma photopeak which is statistically significant: the 2.615-MeV gamma ray of ^{208}Tl. The thallium isopleth is shown in Fig. 9.

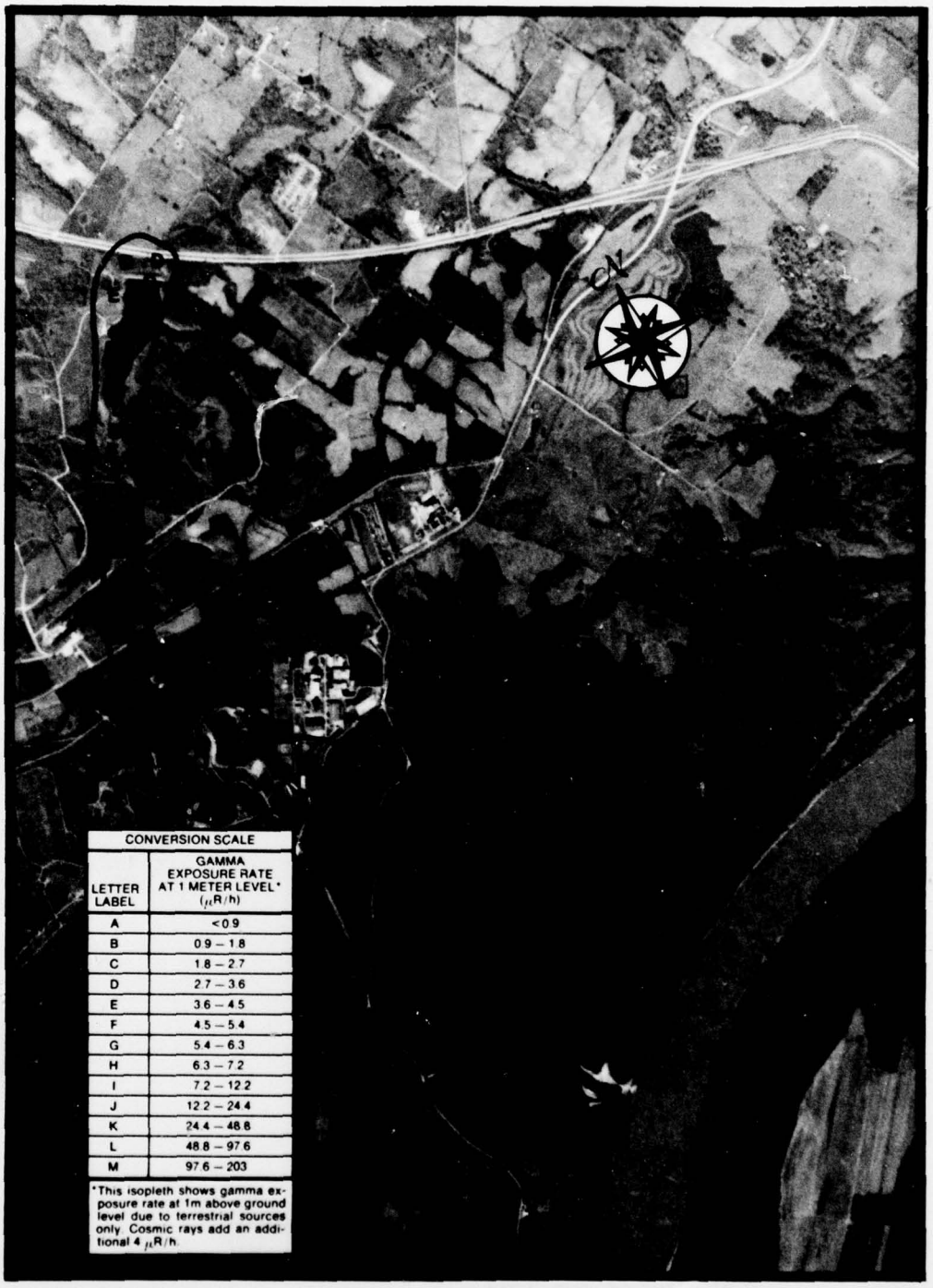
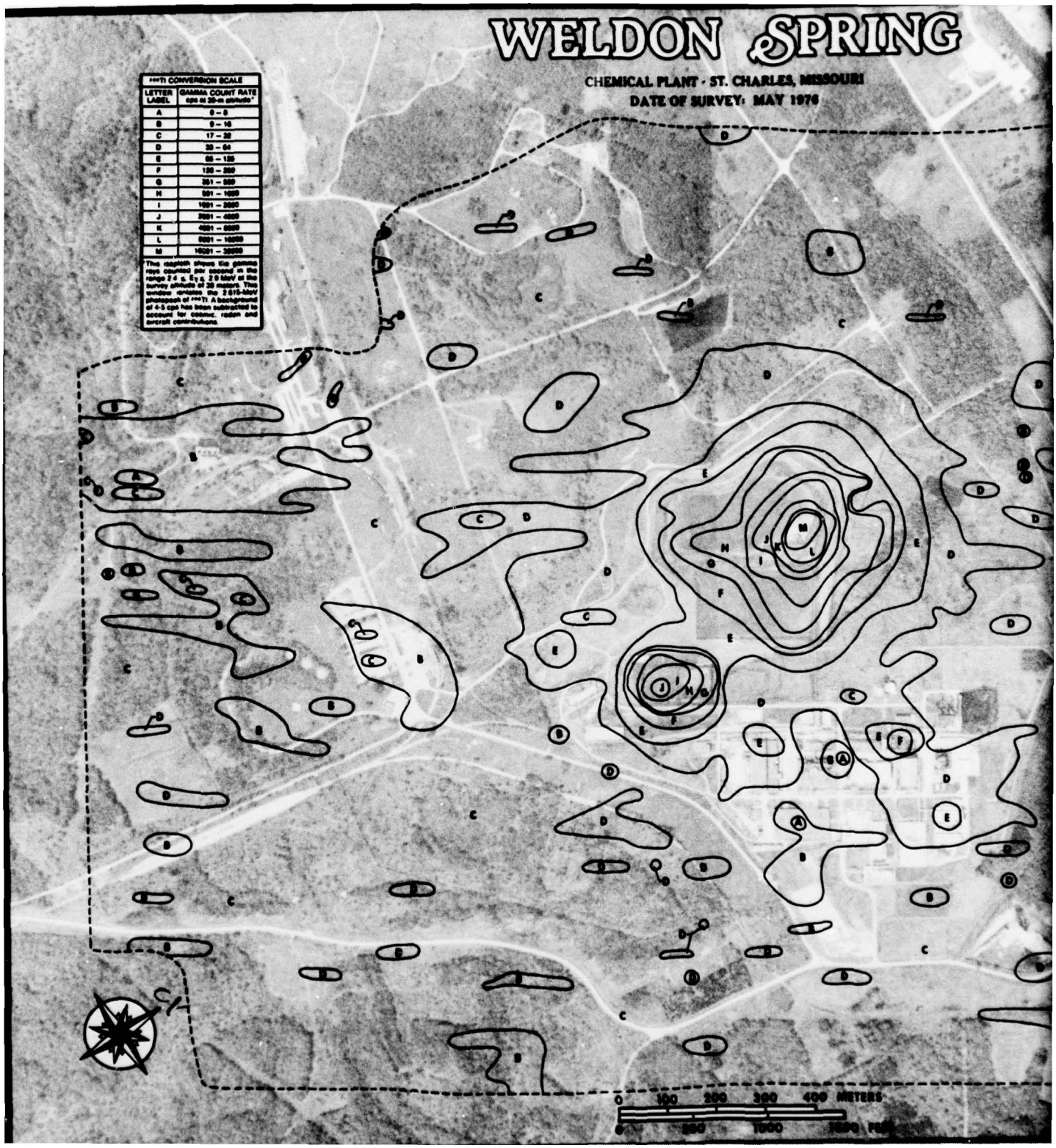
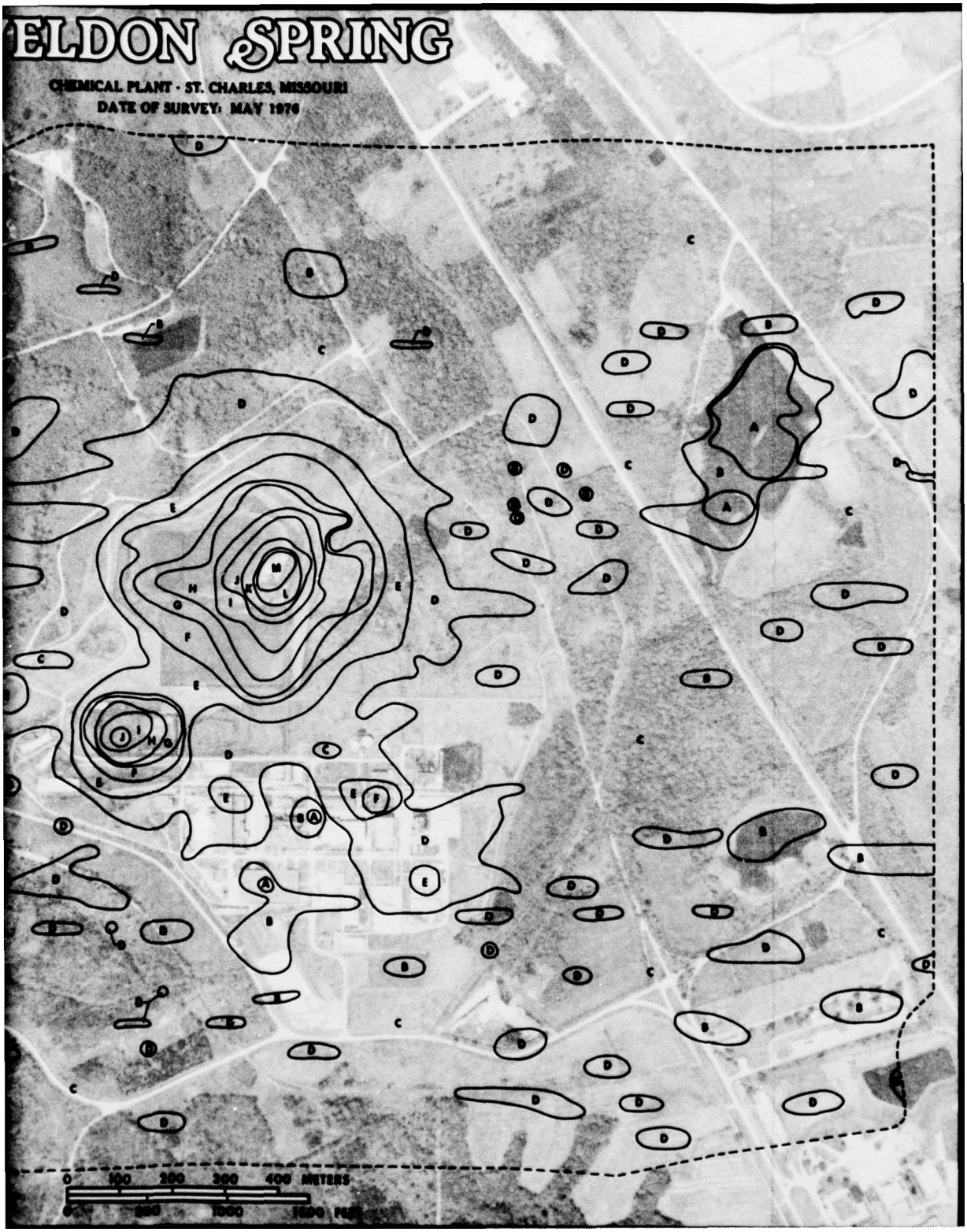


Figure 8. Two special flights were made. Shown above are the gross count intensities from Raffinate Pits 1 and 2 to the Missouri River and from the northwest corner of the Site to (and around) Lake 35. The first was flown at 60-m, the second at 30-m altitude. Only natural activity was measured off-site.


WELDON SPRING
CHEMICAL PLANT · ST. CHARLES, MISSOURI
DATE OF SURVEY: MAY 1976
0 100 200 300 400 METERS


ELDON SPRING
CHEMICAL PLANT - ST. CHARLES, MISSOURI
DATE OF SURVEY: MAY 1976
0 100 200 300 400 METERS

Note that the conversion scale is given simply in counts per second. The maximum for each level is double that of the previous. No point is served by converting to exposure rate the contribution of one isotope. A background of 4-5 cps has already been subtracted from the data to account for cosmic, radon and aircraft contributions.

^{208}Tl is a daughter product of the ^{232}Th in natural thorium. Since ^{232}Th occurs naturally in soil everywhere, slightly varying concentrations of ^{208}Tl will be observed over terrain uncontaminated by human operations. Although thorium itself has a long half-life (1.39×10^{10} year), its daughters are relatively short-lived. Since the longest-lived daughter, ^{228}Ra, has a half-life of only 6.7 year, sufficient time has elapsed for measurable quantities of ^{208}Tl to accumulate in thorium brought to the WSCP for processing. Hence, any unnaturally high concentrations of ^{208}Tl activity can be attributed to imported thorium.

The natural thallium level near the Site is a C: 17-32 cps. Frequent excursions to B or D levels are apparent and expected. Note that water bodies must be large, like Lake 36, to effect a significant change in the count rate. Water bodies and other low-level concentrations are not as well-defined as in the gross count isopleth because the counting statistics are much poorer

The highest concentrations of thorium wastes were apparently dumped in Raffinate Pits 4 and 2. The contour centered on the northeast corner of Pit 4 indicates a very high concentration on or in the mud flats there. Much exposed waste, loose and in containers, is easily visible. The radiological effect is exaggerated by the absence of an attenuating layer of water. Thorium wastes covered by several feet of water would be attenuated in an aerial survey.

The G through I contours centered on Pit 4 are perturbed near the northeast corner of Pit 3. This suggests that thorium wastes were also dumped there. Again the effect is exaggerated by the shallow water and mud flats in that corner of Pit 3.

Activity centered on Pit 2 is only one-eighth as strong as that on Pit 4. Absolute and relative activity levels will vary with water level in the Pits. At times Pits 1 and 2 may be covered with several inches of rainwater. At the time of this survey Pits 1 and 2 had no water cover, revealing a semi-solid surface appearance. Pit 1 barely perturbs the contours centered on Pit 2; hence little thorium waste would be expected in Pit 1.

About 200m southwest of Pit 2 is an E contour about 75m in diameter. This corresponds well with a waste dump just inside the Site fence-line. Since an E level is above natural activity, it would appear that low concentrations of thorium waste were discarded in this dump.

About 150m northeast of Pit 1 is another E level, centered on the northwest end of Bldg. 301, the Metals Plant. This building contained equipment for reduction of uranium tetrafluoride to uranium metal. Since this area appeared as a fairly strong source on the gross count map, the present data would indicate that at least a portion of this activity is due to thorium and its byproducts. Ground-level sampling will be required to determine whether the source(s) are on the Metals Plant roof, on surrounding land, or in the building. Sampling will also determine what portion of the activity can be attributed to uranium and to thorium.

Gamma activity within processing buildings, especially that due to uranium, may be partially shielded from aerial view. The mass of the radioactive material in the building, the distribution inside, the thickness of containers, processing equipment, building walls and ceilings, etc. all affect the radiation isopleth measured from an aerial platform.

Large expanses of concrete or asphalt frequently show a substantial decrease in ^{208}Tl activity because paving materials were deficient in thorium. This appears to be the case over the manufacturing complex of the Plant. Note the A contours near Bldg. 103 and over Bldg. 408, and the B's over asphalt parking lots.

A deficiency of natural thorium in and around these buildings would tend to accentuate the presence of imported thorium. Hence, the E's over buildings 301 and 403 (Chemical Pilot Plant) and the F over Bldg. 102 (Refinery Tank Farm) probably indicate real concentrations of thorium compounds or by-products. Note that Bldg. 201, the Green Salt Plant, shows a deficiency in thorium. On the gross count isopleth (Fig. 7) there is enhanced activity: a K level. Contamination in this area is therefore due primarily to uranium and its by-products. This was anticipated because building 201 contains the major equipment for conversion of uranium trioxide to uranium tetrafluoride.

Contour levels as high as H overlap the fence-line east of Raffinate Pit 4. This is probably due to the shine effect caused by a heavy concentration of thorium waste in Pit 4. As in Fig. 7, however, the interpreter must point out that the shine effect could obscure low-level thorium waste outside the fence line. Using the E level as a criterion one can conservatively say that major concentrations of thorium compounds and by-products are on Site or within 125m of the fence-line.

7.3 GAMMA SPECTRA

Gamma isopleths permit the analyst to show, as a function of position over the survey site, the gamma intensity within an energy window or combination of windows. Another valuable tool is the spectrum, which sorts photons according to their energy. By analyzing a spectrum, one can identify the strong contributing radioelements in the source.

Gamma spectra generated by NaI detectors must be analyzed with some care. As indicated in the previous report,[17] the poor resolution of NaI (approximately 8-10%),[18] coupled with the large number of photopeaks in the uranium and thorium decay series, means that closely-spaced peaks may merge inseparably. However, if a background subtraction is carefully made the analyst can frequently identify the major contributors in a mixed gamma ray source.

Figure 10 shows a spectrum obtained along line 13, near and over the WSCP parking lot. On the flight line map, Fig. 2, these data were accumulated along line segment A.

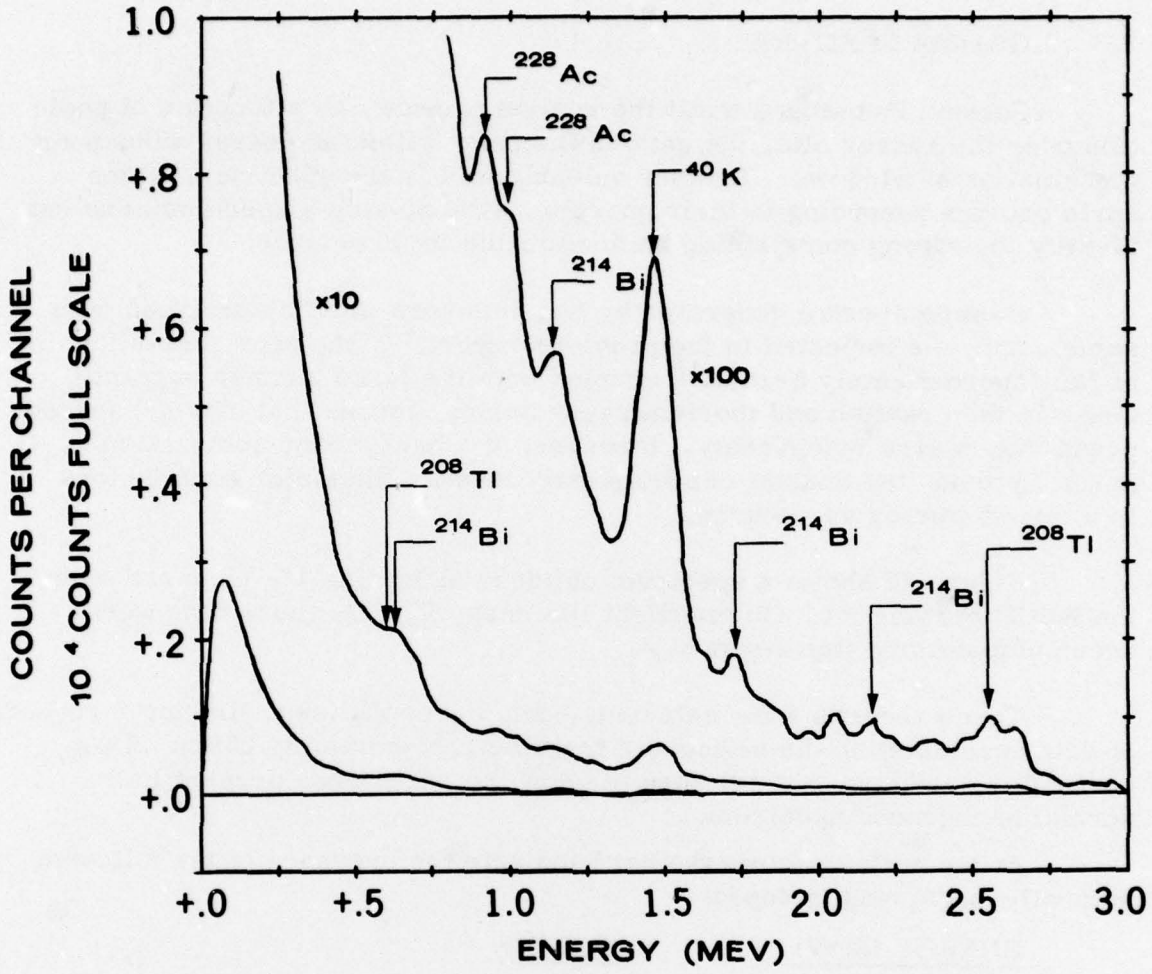
Three records were selected, each 3 seconds long. During 9 seconds of data accumulation the helicopter traveled approximately 265m. This particular spectrum was selected to show the photopeaks present in a normal background spectrum.

At least nine photopeaks here indicate the presence of the following naturally-occurring isotopes:

ENERGY (MeV)	ISOTOPE
0.583	^{208}Tl
0.609	^{214}Bi
0.911	^{228}Ac
0.969	^{228}Ac
1.120	^{214}Bi
1.461	^{40}K
1.764	^{214}Bi
2.204	^{214}Bi
2.615	^{208}Tl

17 Jobst, op. cit.

18 The FWHM (full width at half of the maximum photopeak height) is commonly used as a measure of detector resolution. For the thallium photopeak at 2.615 MeV this width is frequently 200-260 keV.



SPECTRUM NO. SC271(18,20)
DATE 5/13/76-1
LIVE TIME (MIN) +.144
INTEGRATED CT. +.6774537E+05
TYPE WELDON, BKGD NF NEAR PARKING LOT
ALTITUDE 30 M
AIRCRAFT H-500 HELICOPTER

Figure 10. A background spectrum obtained over the WSCP parking lot and surroundings.

Note that the spectrum has been displayed three times in Fig. 11, each time magnified by a factor of 10. Because of the relatively poor resolution of NaI detectors, the photopeaks of other natural isotopes may be hidden or obscured by nearby photopeaks of greater abundance.

The last scale magnification shows the spectrum at 100 counts, full scale. At this magnification many apparent photopeaks can be caused by statistical fluctuations, especially in the high energy portion of the spectrum. Obviously, extreme care must be exercised in the interpretation of these spectra. Although longer spectra can be selected to improve statistics, a larger sample of land area must thereby be accepted with a concomitant degradation in spatial resolution.

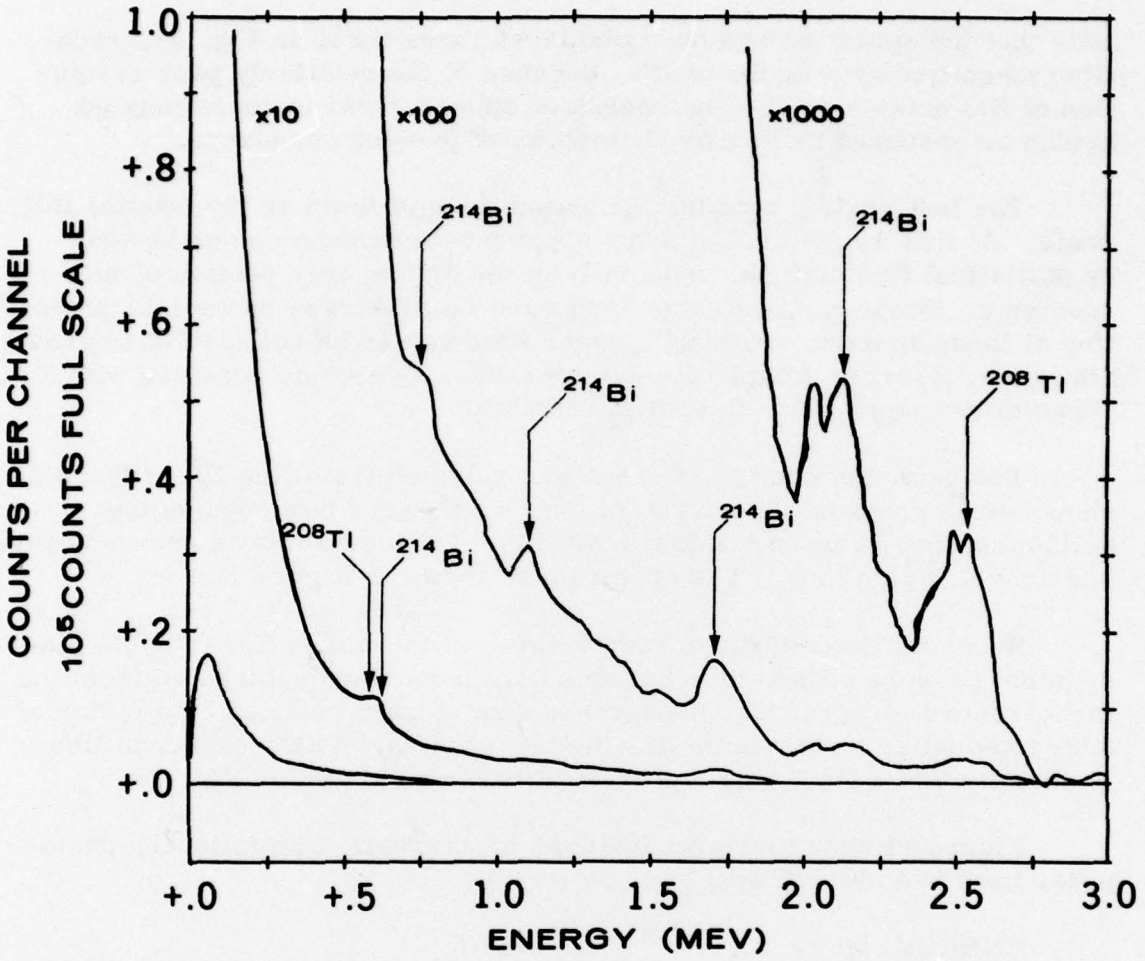
The next spectrum of interest was selected from line 30. Figure 2 shows three records (9 seconds) of data which were recorded as the helicopter flew between the Raffinate Pits. On Fig. 2 this is shown as line segment B, 265m long. The spectrum is shown in Figure 11.

Records fifteen through twenty-three of this same line (Fig. 2, line segment C) were chosen as a suitable background and subtracted from the three-record foreground. Background counts were reduced by a factor of 0.27 to equalize the live time for the two spectra. The background line is actually 735m long; only a portion of it can be shown on Fig. 2.

Figure 11 shows several features of interest. The following photopeaks have been identified:

ENERGY (MeV)	ISOTOPE
0.583	^{208}Tl
0.609	^{214}Bi
0.769	^{214}Bi
1.120	^{214}Bi
1.764	^{214}Bi
2.204	^{214}Bi
2.615	^{208}Tl

Since a normal background has already been subtracted, the prominence of ^{214}Bi and ^{208}Tl in the present spectrum indicates a heavier-than-normal accumulation of materials which ultimately decay into these isotopes. The ^{214}Bi is a daughter of ^{238}U and ^{208}Tl is a daughter of ^{232}Th. The uranium and thorium both have low energy X-rays which are obscured in the Compton tails of the many other isotopes present in this spectrum.



SPECTRUM NO. 326:(32,34)-.27(15,23)
DATE 5/13/76-2
LIVE TIME (MIN) +434
INTEGRATED CT. +.3757541E+06
TYPE WELDON , HS-BKGD, L=30
ALTITUDE 30 M
AIRCRAFT H-500 HELICOPTER

Figure 11. A gamma ray spectrum obtained between the Raffinate Pits at WSCP.

In a normal background spectrum the 2.615-MeV peak of ^{208}Tl is generally more prominent than the 2.204-MeV peak of ^{214}Bi. Here they are reversed, indicating that uranium by-products may be quite heavy in this region. No estimate of relative concentrations of uranium and thorium can be made from this spectral data. It should also be noted that the relative and absolute variations in the concentration of these two elements could vary considerably over the sample interval (approx. 265m). Fig. 11 is quite typical of spectra obtained over the WSCP. The ^{214}Bi appears to be quite prominent in the region of the Raffinate Pits.

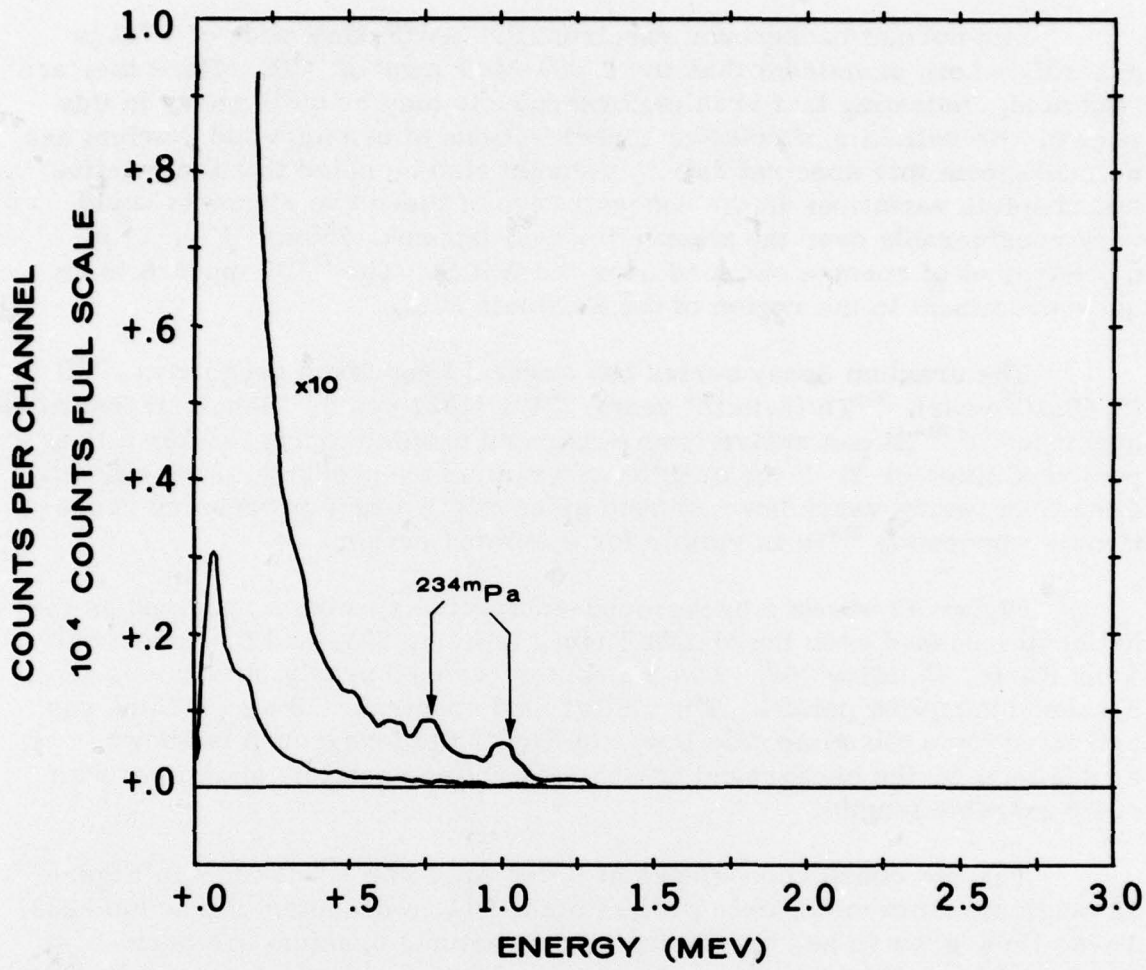
The uranium decay series has several long-lived daughters: ^{234}U (2.48×10^5 year), ^{230}Th (8.0×10^4 year), ^{226}Ra (1622 year). Hence, measurable quantities of ^{214}Bi can evolve from separated uranium only: 1) after a long period of time; or 2) if the quantity of uranium by-products is very great. Less than twenty years have elapsed since WSCP began processing operations. Apparently ^{214}Bi is visible for the latter reason.

Figure 12 shows a background-subtracted spectrum acquired as the helicopter passed over the Metals Plant, Building 301, and the Green Salt Tank Farm, Building 202. The helicopter covered nearly 90m during the 3-second sampling period. The background spectrum (18 sec, 515m) was extracted from the same data line. In Fig. 2 the foreground is shown as segment D, the background as segment E (incompletely shown because of its extreme length).

The two conspicuous peaks at 0.766 MeV and 1.001 MeV in Figure 12 originate from metastable protactinium-234, a daughter of uranium-238. These lines grow in and predominate when natural uranium has been separated from its daughters. The other, less prominent, photopeaks that appear in this spectrum are not inconsistent with those expected from other daughters in the uranium decay series.

8. CONCLUSION

A helicopter survey of the Weldon Spring Chemical Plant was conducted from May 11-14, 1976. The survey altitude and flight line spacing were both 30m. Of 63 flight lines flown over the Plant and its immediate surroundings, 37 showed abnormal levels of radioactivity which may be attributed to Plant operations. A gross count gamma exposure rate isopleth and a ^{208}Tl (thallium) count rate isopleth have been superimposed on aerial photographs of the Site to show the distribution of radioactivity. Gamma spectra show that the activity is due to uranium, thorium and daughters of their respective decay series. All detectable



SPECTRUM NO. SC291:(20)—0.152(1,6)
DATE 5/13/76-1
LIVE TIME (MIN) +.044
INTEGRATED CT. +.5101133E+05
TYPE WELDON, BLDG - BKGD, LINE 23
ALTITUDE 30 M
AIRCRAFT H-500 HELICOPTER

Figure 12. A spectrum acquired over the Metals Plant and Green Salt Tank Farm at WSCP.

activity above background levels is on Site or within 200m of the fence line surrounding the Weldon Spring Chemical Plant. Greater precision in isotope identification and mapping can be achieved only through in situ measurements and soil samples.

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